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Phase-Contrast X-ray Imaging of Cryogenic Fuel Layers in Beryllium Shells

We have demonstrated, for the first time, the ability to measure the smoothness of deuterium-tritium (DT) fuel inside of an optically opaque ignition capsule. NIF ignition targets require a smooth, spherical layer of DT ice on the inside of the ~2-mm diameter fuel capsules. Critical to forming a layer of the required smoothness is quantitatively characterizing the ice surface roughness with the target cooled to cryogenic temperatures (~19 K). For transparent capsules, such as plastic, the fuel layer can be viewed and characterized optically. However, beryllium capsules, which are the most attractive in recent indirect-drive ignition target designs, are opaque and do not allow visible light measurements of the DT fuel.

In collaboration with Los Alamos National Laboratory scientists, we have demonstrated characterization of the DT ice layer using a method called phase-contrast x-ray imaging. Traditional x-ray imaging relies on the absorption of x-rays to locate internal structure. However, the x-ray absorption in solid DT is too weak compared to that of the beryllium to provide sufficient contrast. Phase-contrast imaging takes advantage of the small refraction and diffraction of x-rays to provide image contrast. The strongest deflection occurs wherever there is a sharp change in the x-ray refractive index, such as at boundaries between materials. Thus, the ice-beryllium and ice-vapor boundaries are made easily visible by the phase-contrast imaging method. This is shown schematically in Figure 1. The technique has been used in the biological field to image small-scale structures that have very

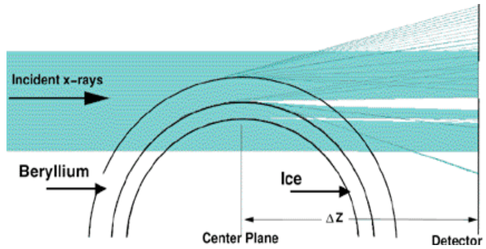

Fig. 1. Phase-contrast x-ray imaging uses small x-ray deflections to provide contrast. A collimated beam of x-rays will be refracted and diffracted near the material interfaces. The deflected x-rays produce contrast on a detector placed a distance ΔZ away from the shell (this schematic greatly exaggerates the deflection to illustrate the technique).

low absorption contrast. An x-ray source with high spatial coherence, such as a synchrotron beam or new microfocus anode sources, is required.

In our recent experiments we constructed a phase-contrast x-ray apparatus that integrated a microfocus source and detector, a cryostat for cooling the capsule and its fuel, and a tritium source, which provides the fuel through a micro fill tube. With this apparatus we obtained images of a beryllium capsule showing a DT liquid meniscus transitioning through freezing to a smooth ice layer, as seen in Figure 2. The layer forms through a natural process in which the ice redistributes itself due to the internal heat generated by the radioactive decay of tritium. The process is called beta-layering, and only requires that the outside surface of the capsule have a very uniform temperature. Our previous optical measurements in transparent shells have measured beta-layered DT fuel with surface smoothness better than needed for ignition. The images in Figure 2 are the first ever recorded of the beta-layering process in a beryllium shell. The measurement technique is also applicable to optically transparent shells, and may provide an improvement over the optical method we have used previously.

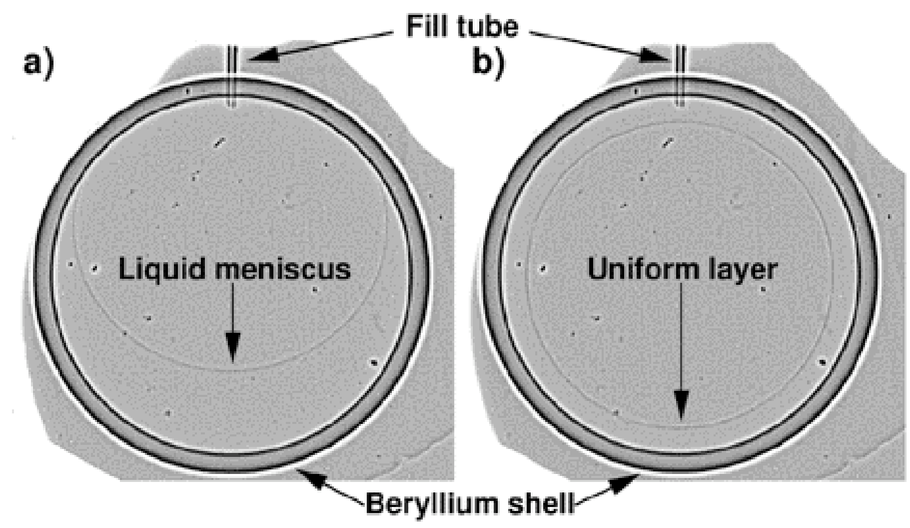

Fig. 2. Phase-contrast enhanced x-ray image with (a) liquid deuterium-tritium and (b) solid deuterium-tritium in a beryllium shell. The image was processed with a band-pass filter to enhance the edges. In both cases, gravity is toward the bottom of the image. The liquid was slowly cooled through the melting temperature to the solid state. The radioactive self-heating causes the solid to redistribute to a spherical shape.

For comments about content of the ***Bimonthly Update,*** contact Bruce A. Hammel (925) 422-3299.
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